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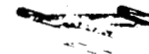
***AN OVERVIEW OF THE PLANNED
INFLATABLE SYNTHETIC APERTURE RADAR
SPACE DEMONSTRATION***

Michael C. Lou

***A presentation at the ASAR Workshop
September 27 and 28 ,1999, Montreal, Quebec, Canada***

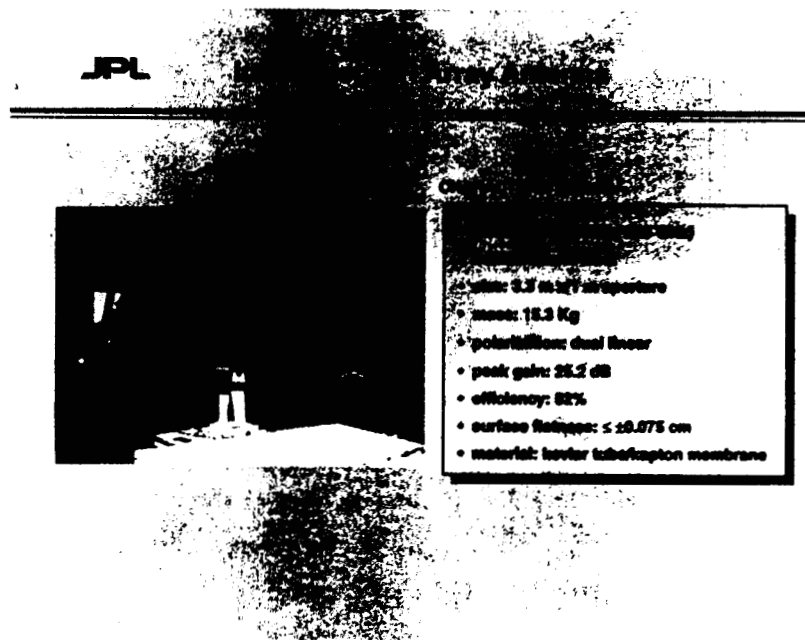


Inflatable SAR Space Demonstration



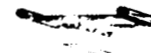
Background

- Two 1/3-scale engineering models were designed, fabricated, and assembled.
- ILC-Dover SAR:
 - Urethane coated Kevlar frame
 - Controlled deployment using constant force springs
 - Catenary system to control membrane flatness and separation
 - $<1.6 \text{ kg/m}^2$ projected antenna array mass density for full size array
- L'Garde SAR:
 - Self-rigidizable frame using stretched aluminum tubes
 - Controlled deployment using Velcro strips
 - Honeycomb spacers to assure membrane separation and relieve tubes from bending loads
 - $<1.5 \text{ kg/m}^2$ projected antenna array mass density for full size unit
- Advanced microstrip SAR membrane array antenna prototype:
 - 1m x 3.3m aperture composed of 3-layers of RF membrane
 - L-band (1.25 GHz) center frequency
 - 80 MHz bandwidth
 - Dual Polarization (H and V)





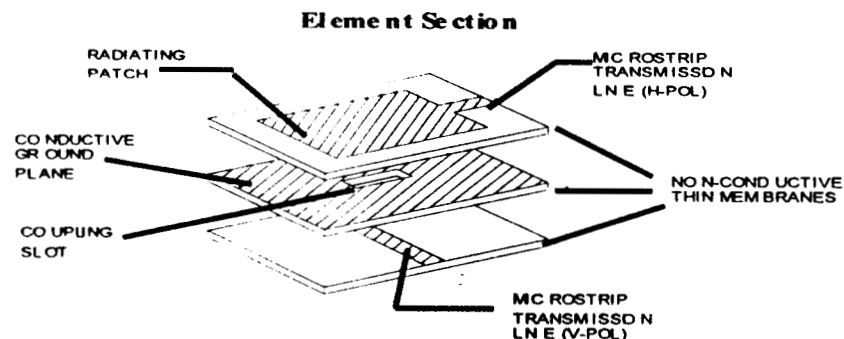
Inflatable SAR Space Demonstration



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Inflatable Microstrip SAR RF Design

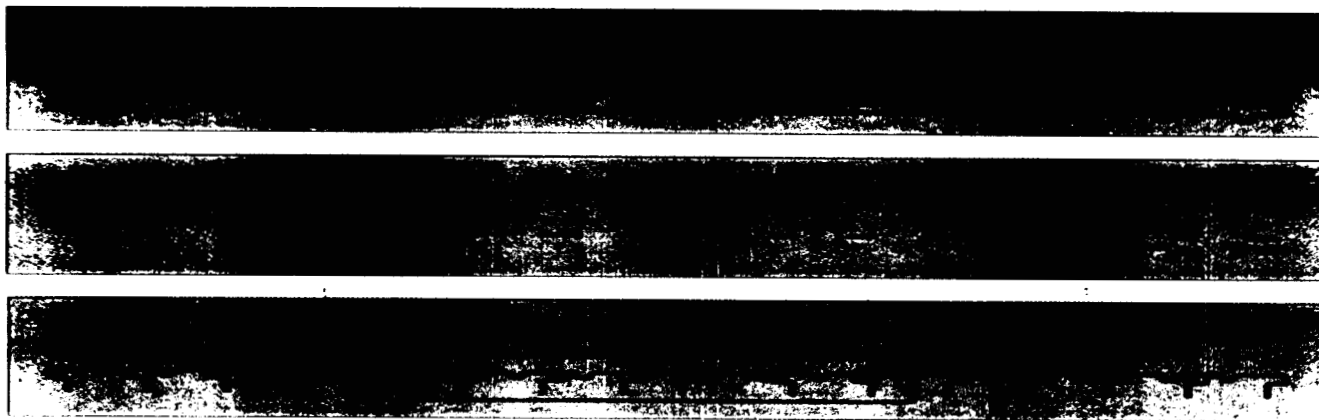
Tri-Layer Inflatable Microstrip Antenna



ALL METAL LAYERS ARE 5 MICRON THICK EACH
ALL THIN MEMBRANES ARE 50-MICRON (2 MIL) THICK EACH

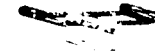
- PRINTED MICROSTRIP PATCH ARRAY WITH AIR SUBSTRATE USING THIN MEMBRANES, TOP 2 MEMBRANES SPACING = 0.5", BOTTOM 2 MEMBRANES SPACING = 0.25"
- THIN MEMBRANE HAS 5-MICRON COPPER ON 2-MIL KAPTON® (5-MICRON COPPER => 2 SKIN DEPTH AT L-BAND)
- MICROSTRIP POWER DIVIDER LINES USE PARALLEL/SERIES COMBINATION PARALLEL TO ACHIEVE BANDWIDTH, SERIES TO MINIMIZE NEEDED REAL ESTATE
- 3 MEMBRANE LAYERS:
 - top layer has radiating patches and horizontal-pol power divider lines
 - middle layer is ground plane with aperture coupling slots
 - bottom layer has vertical-pol power divider lines
- CENTRAL FEED PROBES ALLOW CONNECTION TO T/R MODULES AND PHASE SHIFTERS FOR ELECTRONIC BEAM SCANNING IN ONE DIMENSION

Inflatable Microstrip SAR Array Dual-Pol Aperture Coupled 3 Membrane-Layers



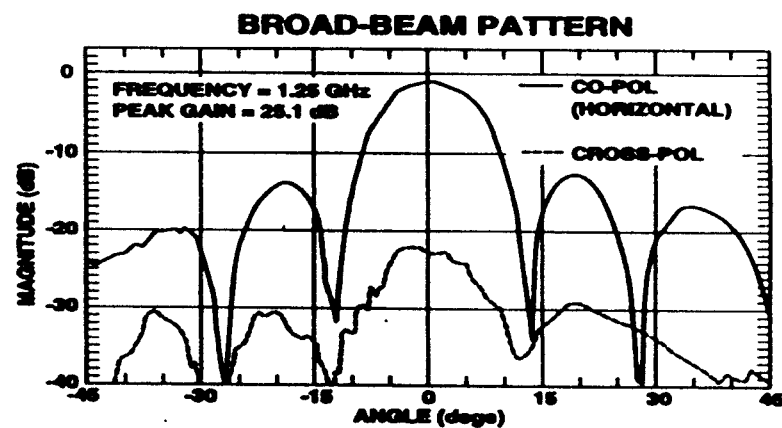
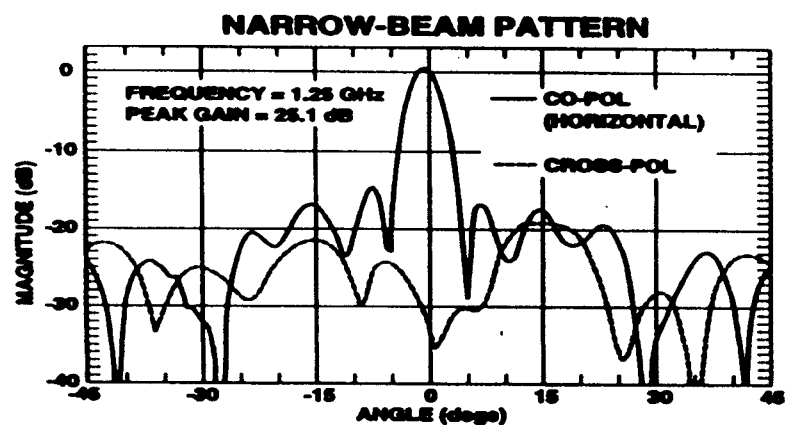
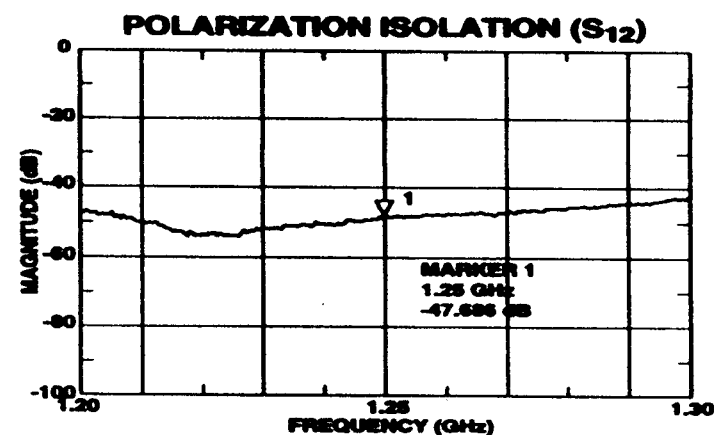
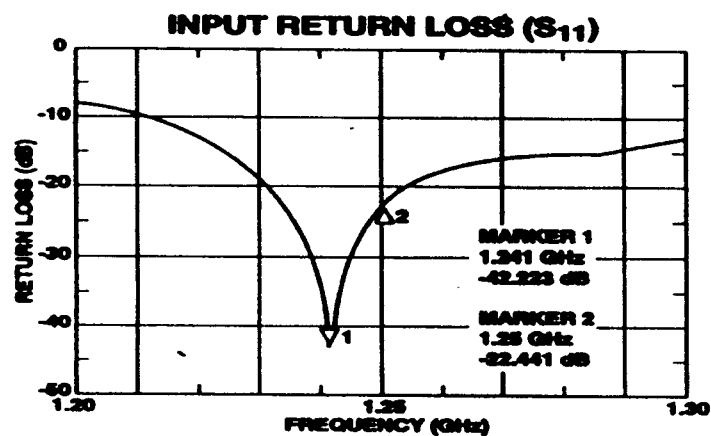


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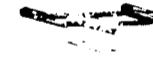
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INFLATABLE SAR ARRAY ANTENNA RF TEST RESULTS





Inflatable SAR Space Demonstration



Comparison of Space SARs

Parameter	SeaSat	ERS-1	JERS-1	RadarSat	SIR-C	Inflatable SAR (Projected)
Year of Launch	1978	1991	1992	1995	1994	TBD
Frequency & Bandwidth	L-Band (1.25 GHz)	C-Band (5.3 GHz)	L-Band (1.25 GHz)	C-Band (5.3 GHz \square 32 MHz)	L&C-Band (1.25 GHz \square 15 MHz) (5.3 GHz \square 15 MHz)	L-Band (1.25 GHz \square 40 MHz)
Aperture Size [m]	2.2 x 10.8	1 x 10	2.2 x 10.8	1.5 x 15	2.95 x 12 (L) 0.75 x 12 (C)	3 x 10
Mass [Kg]	103 ⁽¹⁾ 260 ⁽²⁾	85 ⁽¹⁾ 185 ⁽³⁾	139 ⁽¹⁾ 296 ⁽⁴⁾	680 ⁽²⁾	450 ⁽¹⁾ 7727 ⁽²⁾	48 ⁽⁵⁾
System Mass per m ² of Aperture Area [Kg/m ²]	10.9	18.5	12.5	30.2	Heavy	1.6 ⁽⁵⁾

⁽¹⁾ Antenna array only

⁽²⁾ Including support structure and deployment mechanisms

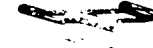
⁽³⁾ Including 100 kg of estimated support structure and deployment mechanisms

⁽⁴⁾ Including 157 kg of estimated support structure and deployment mechanisms

⁽⁵⁾ Not including mass of launch constraints



Inflatable SAR Space Demonstration



Inflatable SAR Space Demonstration

Mission Overview

- Space Shuttle demonstration of Roll-up Inflatable SAR antenna (2-4 day mission)
- Fast technology infusion to radar missions by raising TRL from 4 to 7
- Antenna will transmit and ground stations will receive for lowest cost
- Minimal Shuttle interfaces
- Inflatable SAR planned for early 2002 Shuttle launch
- Benefit from NGST Sunshield Experiment (ISIS) - Similar STSD/HH interfaces, in-orbit operation, extension mast, safety, etc.
- NASA-provided Hitchhiker Cross-bay Bridge
- No Shuttle manifest yet

Experiment Objectives

- Controlled deployment of inflatable structure
- Space rigidization of large planar inflatable structures
- Post-rigidization dimensional stability and structural integrity
- Planarity and spacing control of multiple stretched membrane layers
- On-orbit measurements and mechanical and RF performance verification of a functional inflatable SAR
- Space qualification of lightweight, high performance antenna electronics including T/R modules, power converters and RF, power and control distribution feed compatible with a membrane inflatable antenna
- Launch survivability of inflatable SAR

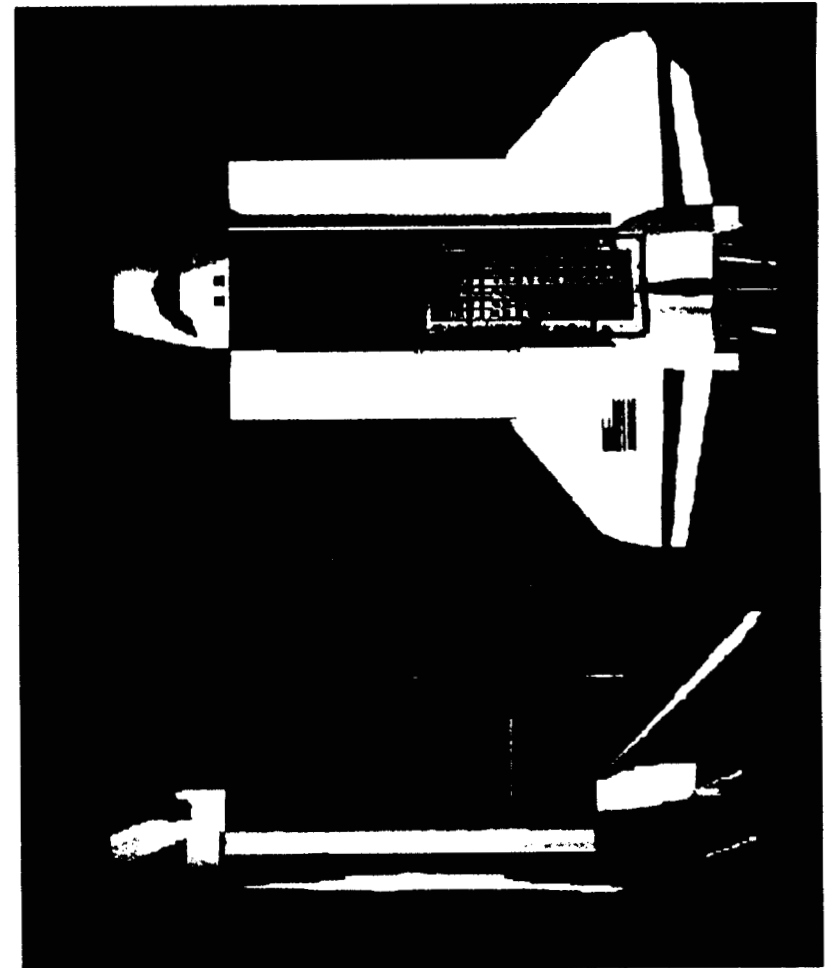


Inflatable SAR Space Demonstration



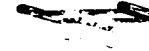
Experiment Description

- SAR antenna consists of 10m x 2.5m planar frame with 3-layer membrane aperture attached to central support platform
- Deployable mast raises the experiment above the cargo bay
- Inflatable SAR is attached to the Hitchhiker (HH) Cross-Bay Bridge structure and uses similar inflation system, release mechanisms, jettison devices, and HH carrier avionics as ISIS
- On-Orbit operating procedures and shuttle safety approaches similar to ISIS, which is scheduled to be launched on STS-107 in late 2000
- Shuttle safety issues concerning inflatable deployment over Shuttle cargo bay and emergency jettison is driver in experiment design
- Experiment mass <280 kg
- DC Power consumption < 650W peak, 10 W average



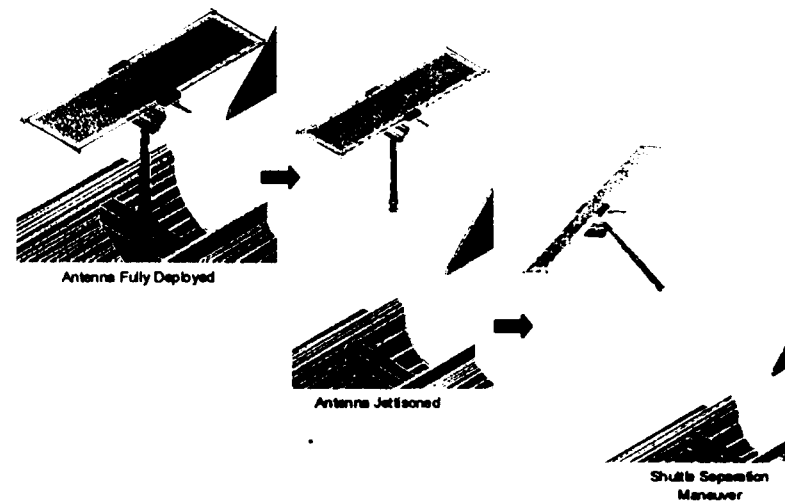
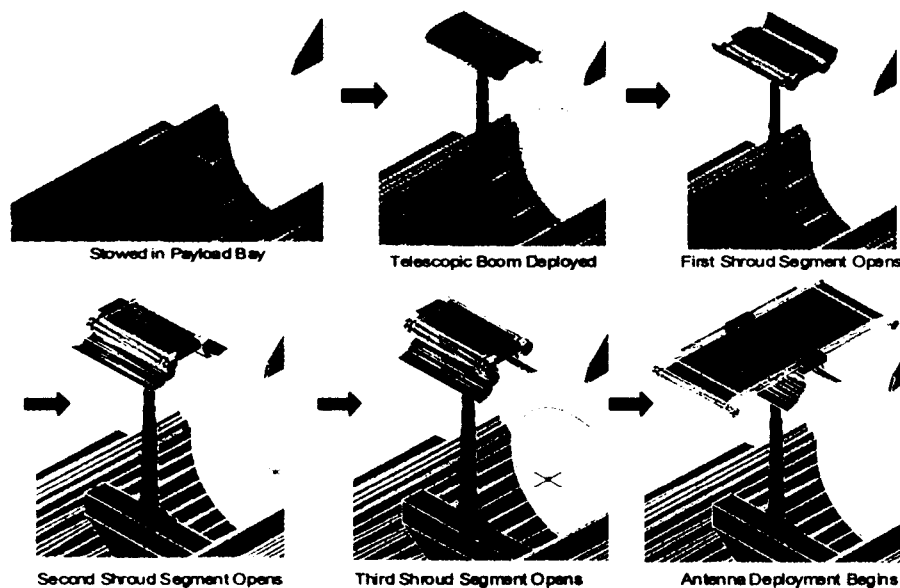


Inflatable SAR Space Demonstration



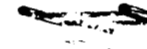
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In-Orbit Operations



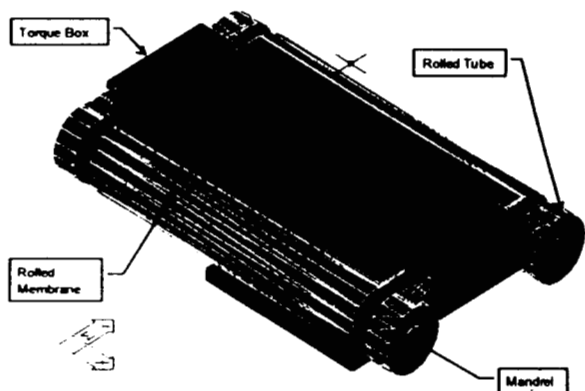


Inflatable SAR Space Demonstration

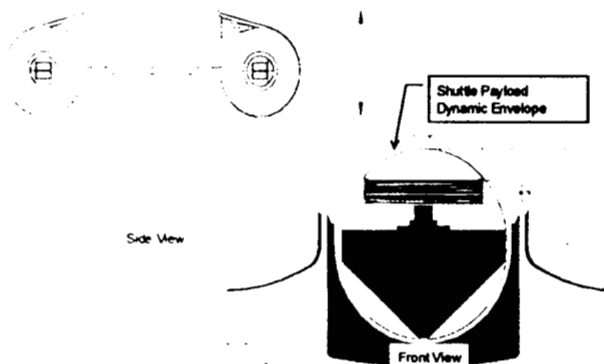


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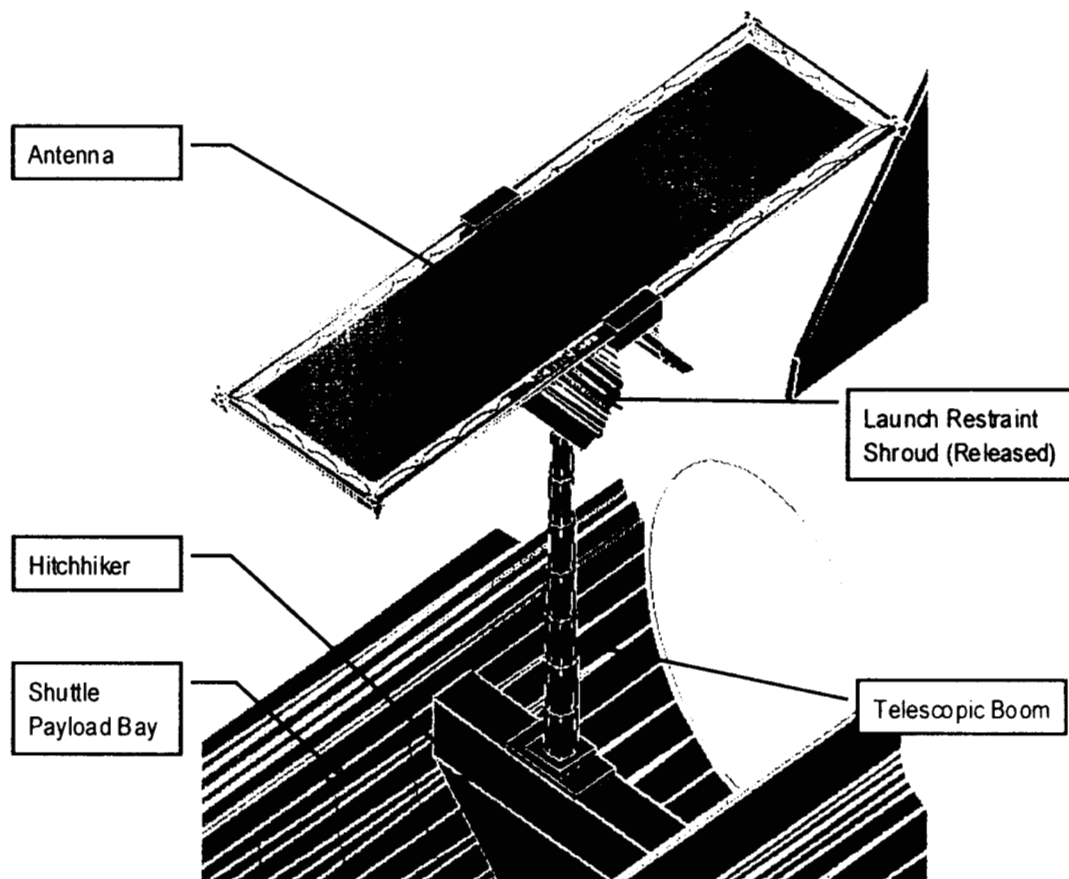
Stowed Configuration



Design Envelopes



In-Orbit Deployed Configuration



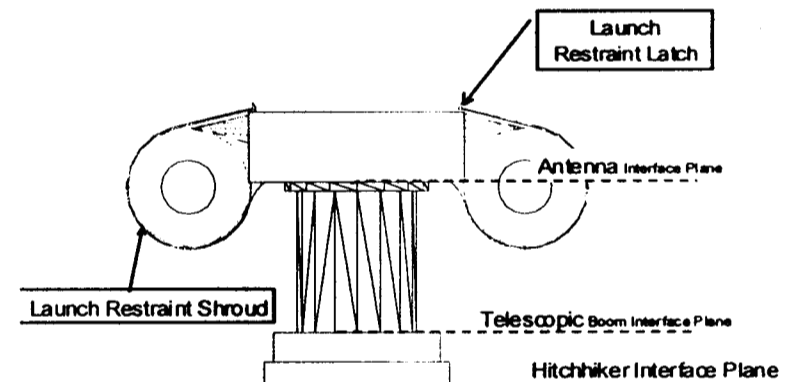
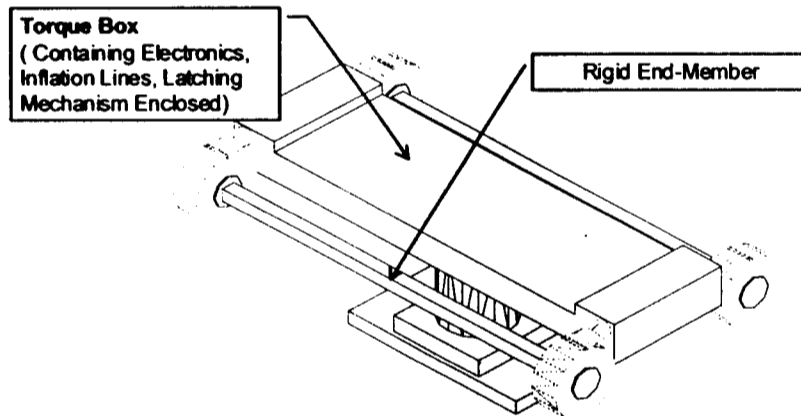
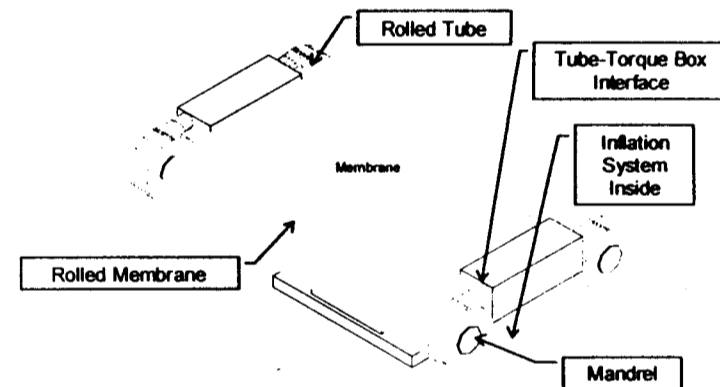
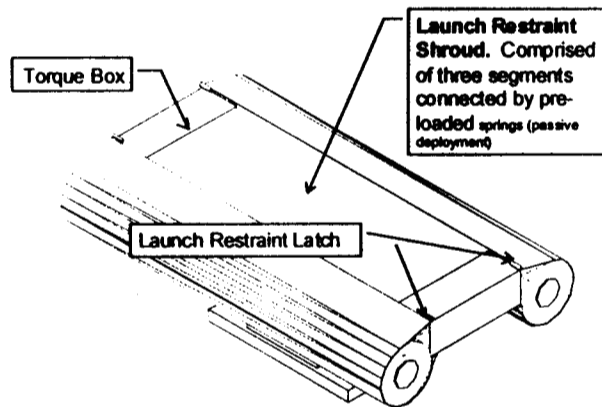


Inflatable SAR Space Demonstration



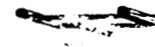
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Mechanical Components



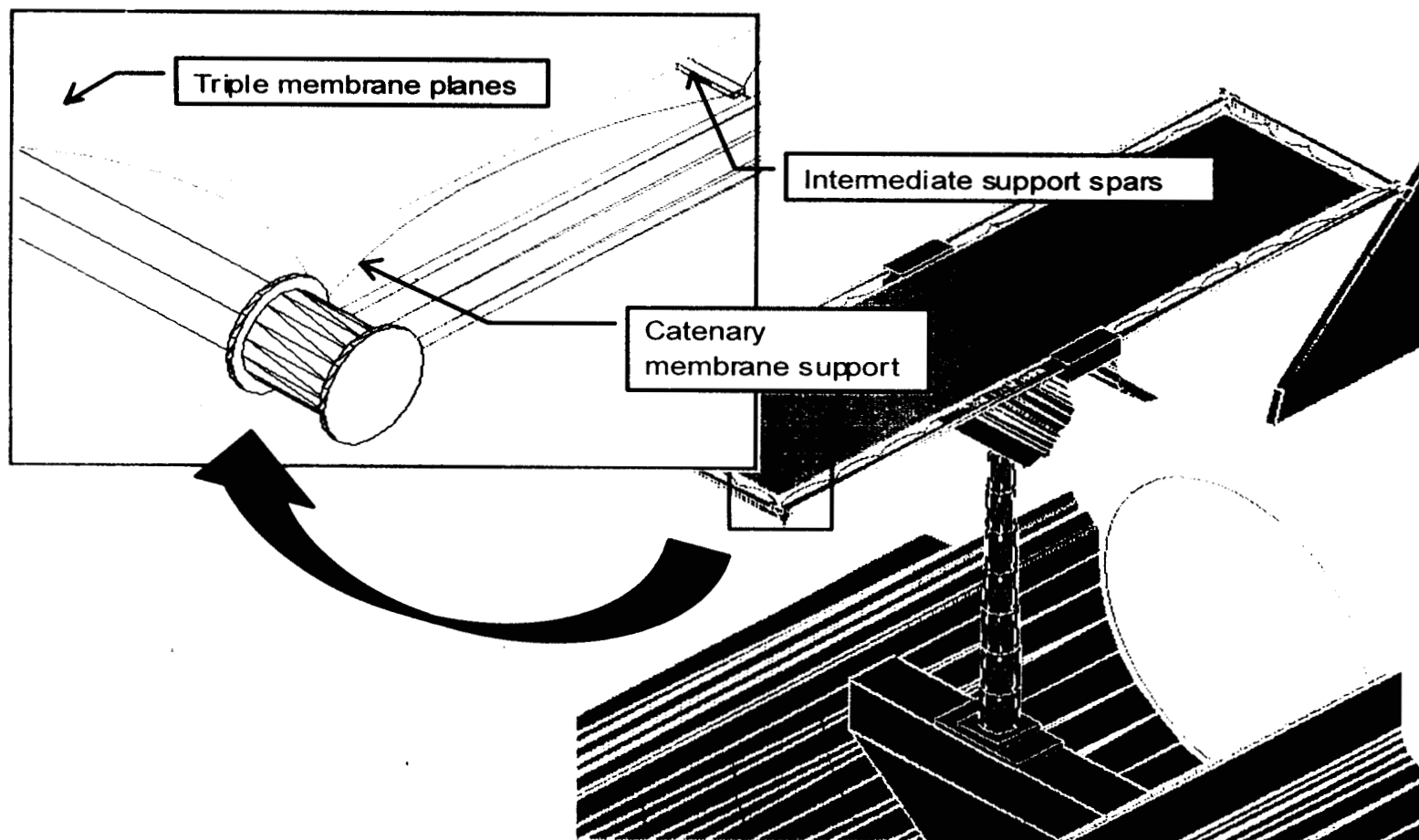


Inflatable SAR Space Demonstration



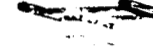
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Membrane and Support Spars





Inflatable SAR Space Demonstration

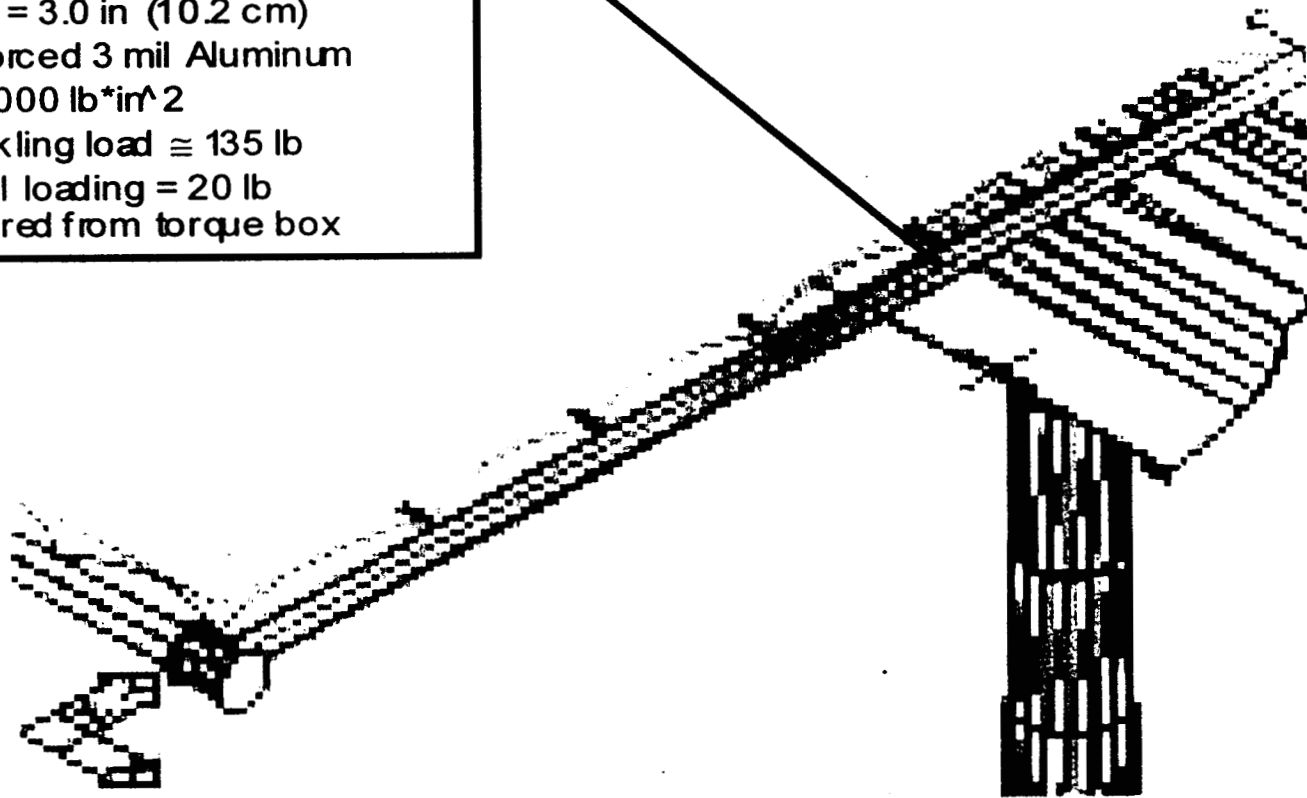


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Inflatable Boom Description

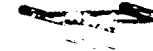
Inflatable/Rigidizable Boom:

- Length = 182.9 in (464 cm)
- Diameter = 3.0 in (10.2 cm)
- Rib-reinforced 3 mil Aluminum
- $EI \cong 600,000 \text{ lb} \cdot \text{in}^2$
- Axial buckling load $\cong 135 \text{ lb}$
- Req axial loading = 20 lb
- Cantilevered from torque box





Inflatable SAR Space Demonstration

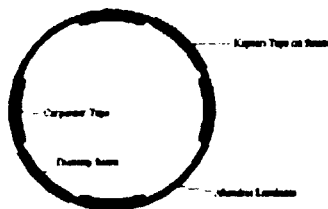


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Spring-Tape Reinforced Aluminum Laminate Booms

Materials and Construction:

- One 3-mil aluminum layer
- Two 1-mil polyester constraining sheets
- Four 1-in-wide spring tapes for reinforcement



Dimensions:

- Length - 5 m
- Diameter--3 in.

Weight:

- Boom - 0.18 kg/m
 - End Caps - 0.7 kg
- Total weight = 1.5 kg

Advantages

- lightweight, easy to package
- high load-carrying capability (even with a very small diameter)
- component materials have space heritage
- no power needed for rigidization
- no outgassing/contamination
- low cost

Axial Buckling Load Tests



Test Scene

Buckling Load Test Results

Tube number	Buckling load
1	118.0 (lbs)
2	114.0 (lbs)
3	135.2 (lbs)
4	149.6 (lbs)
5	134.4 (lbs)
6	136.4 (lbs)
7	165.2 (lbs)

The test boundary is pin-pin.
If the boundary condition is changed to pin-clamped, buckling load would be doubled.

Finite Element Analysis of Axial Buckling Load



Finite Element Model



Zoom in



Buckled Tube

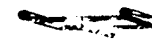
4802 nodes
2460 plate elements
2364 laminate elements

Buckling Load 167 lbs

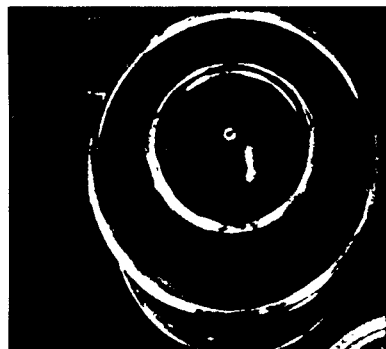
Percentage Difference
Between Test & Analysis
(167-165.2)/167= 1.08%



Inflatable SAR Space Demonstration



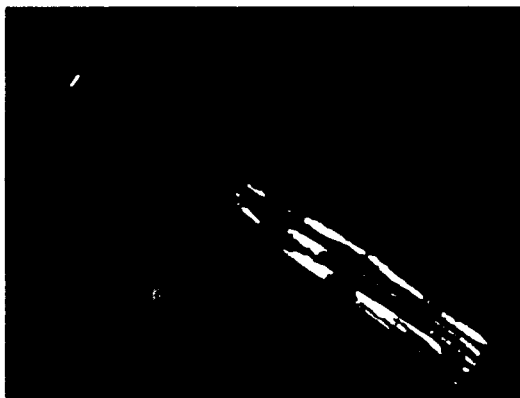
Rolled-Up and Re-Deployment of 5-m Booms



Flattened Booms on Mandrels (6.5" and 12")



Partially Unrolled (On 6.5" Mandrel)



Completely Unrolled

Buckling Load changes Due To Roll-up

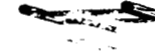
Boom #	Test #	Buckling loads (lbs)	Inflation Time
3	1	135.2 (First Time)	5 minutes
3	2	92.0 (Rolled up)	5 minutes
3	3	89.2 (Rolled up)	5 minutes
3	4	94.0 (Rolled up)	135 minutes
4	5	149.6 (First Time)	5 minutes
4	6	105.6 (Rolled up)	5 minutes
4	7	101.6 (Rolled up)	5 minutes

Observations:

- After a boom is rolled-up and later unrolled, its strength to resist buckling is reduced
- The diameter of the mandrel appears to affect the buckling load somewhat but not in a significant way
- Maintaining pressure for longer time after booms have been unrolled seems to help the buckling capability
- Every Buckling test reduces the buckling capability of the boom

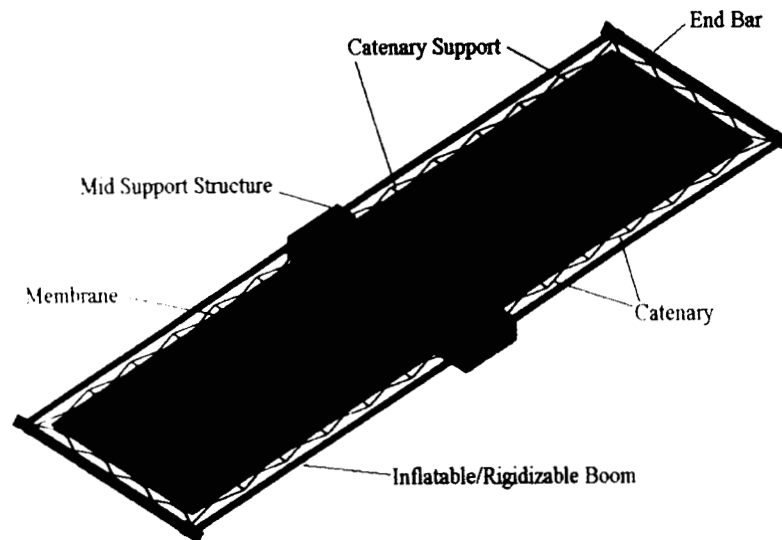


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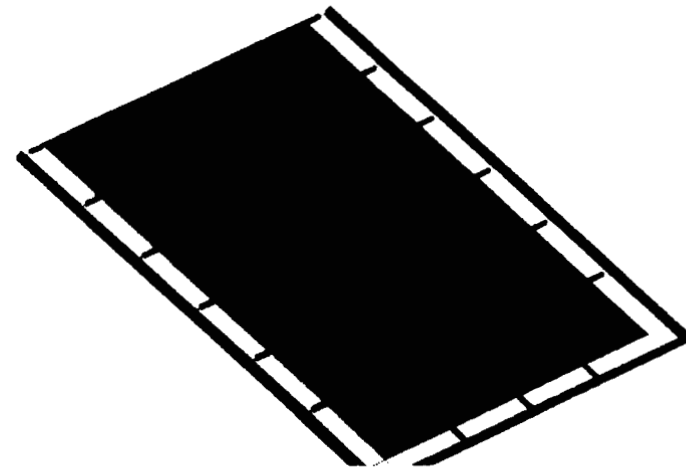


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Finite Element Analysis of Inflatable SAR



Components of Inflatable SAR



One Wing Finite Element Model

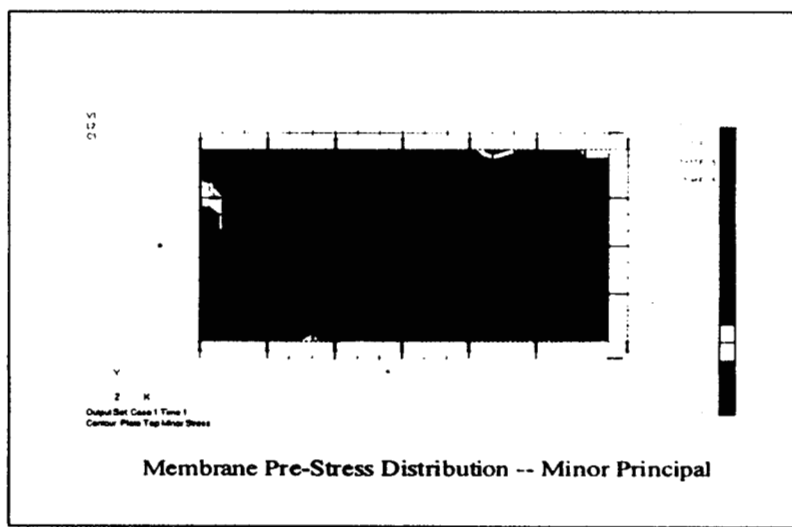
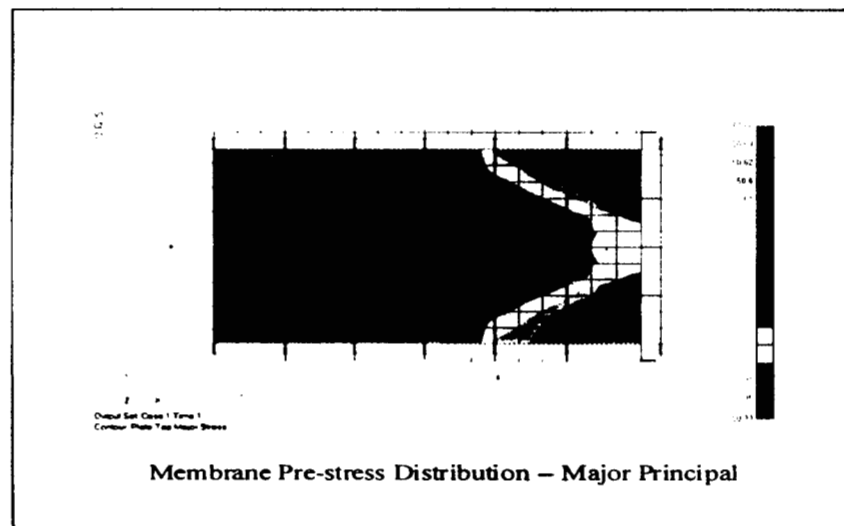
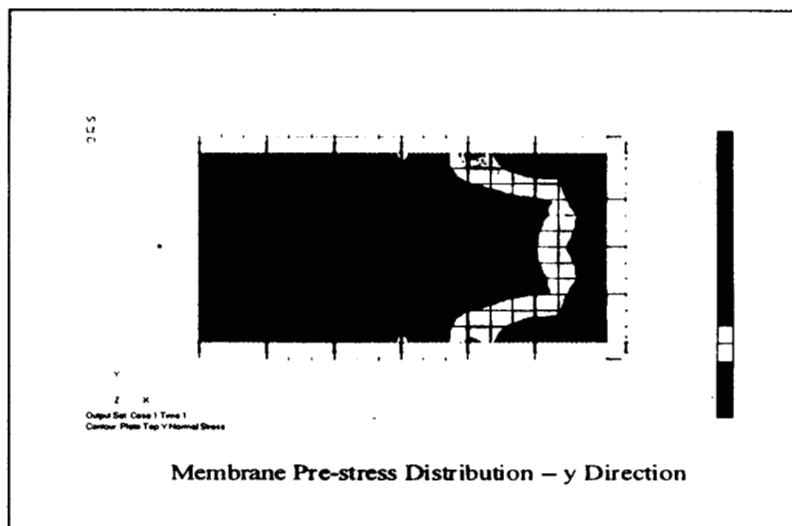
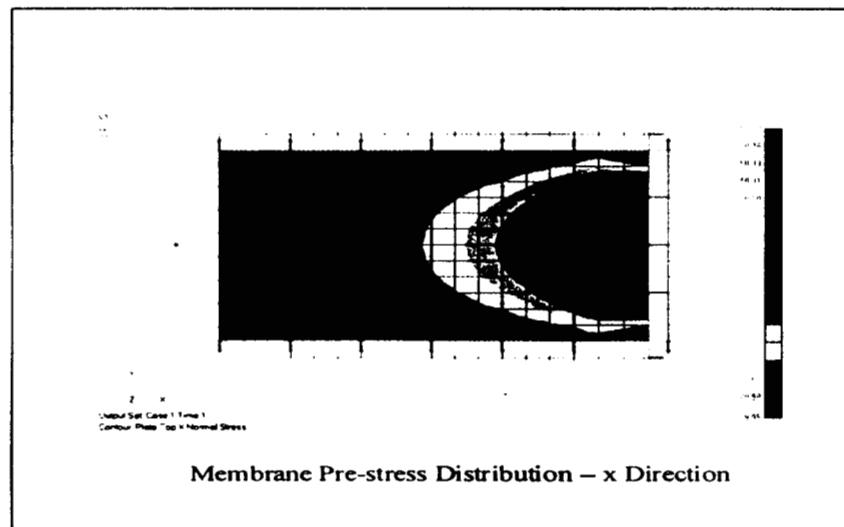


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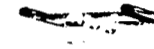
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Static Analysis Results





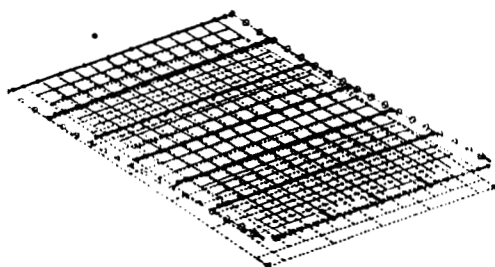
Inflatable SAR Space Demonstration



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Modal Analysis Results

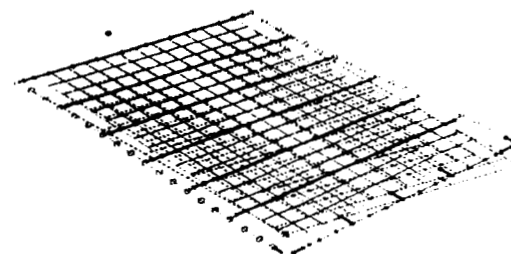
5.00



Output Set Mode 1: 1.158834 Hz
Deformed(7.958) Total Translation

First Mode (With Differential Stiffness)-- 1.16 Hz

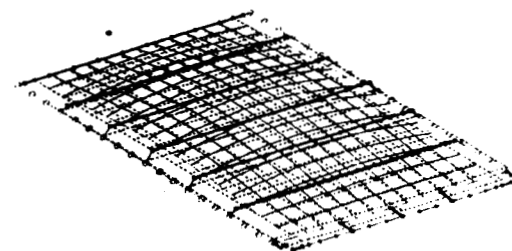
5.00



Output Set Mode 2: 2.683424 Hz
Deformed(8.995) Total Translation

Second Mode (With Differential Stiffness)-- 2.68 Hz

5.00

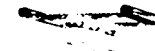


Output Set Mode 3: 3.097579 Hz
Deformed(14.98) Total Translation

Third Mode (With Differential Stiffness)-- 3.10 Hz



Inflatable SAR Space Demonstration



Technology Development Challenges

Inflatable Structures and Mechanical

- Develop Kapton/Aluminum/Kapton laminates
- Build a half-wing full-size engineering model for structural testing and characterization
- Complete mechanical design of launch constraint/release, inflation system, extension mast interface, etc.

Microstrip RF Membranes

- Achieve the same 80 MHz bandwidth with a much longer aperture by using parallel/series feed
- Equalize the radiation efficiencies (gains) for both polarizations
- Etching, bonding, and aligning large membrane pieces
- Achieve 2-D beam scan by distributing the T/R modules over the entire aperture instead of at the central region (for future)

Hi-Performance SAR Antenna Electronics

- 200 Watt L-band T/R modules (45% efficiency, 80 MHz bandwidth)
- T/R modules (18 H-pol, 18 V-pol) distributed in elevation and mounted on the honeycomb support structure for electronic elevation steering
- High-density, high-efficiency DC-DC converters for power distribution
- FPGA-based antenna controller for control and timing
- RF feed network compatible with thin-film membrane technology
- Power and timing distribution feed network compatible with thin-film membrane technology